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The attachment system and physiology in adulthood:

Normative processes, individual differences, and implications for health

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Abstract

Attachment theory provides a conceptual framework for understanding intersections between personality and close relationships in adulthood. Moreover, attachment has implications for stress-related physiology and physical health. We review work on normative processes and individual differences in the attachment behavioral system, and their associations with biological mechanisms related to health outcomes. We highlight the need for more basic research on normative processes and physiology, and discuss our own research on individual differences in attachment and links with physiology. We then describe a novel perspective on attachment and physiology, wherein stress-related physiological changes may also be viewed as supporting the social-cognitive and emotion regulatory functions of the attachment system through providing additional energy to the brain, which has implications for eating behavior and health. We close by discussing our work on individual differences in attachment and restorative processes including sleep and skin repair, and by stressing the importance of developing biologically plausible models for describing how attachment may impact chronic illness.

Keywords: Attachment theory, physiology, cortisol, stress, neuroscience

The attachment system and physiology in adulthood: Normative processes, individual differences, and implications for health

The *attachment behavioral system* was proposed as a psychological regulatory system that promotes safety, survival and security by regulating proximity to nurturing attachment figures (e.g., Bowlby, 1979/2005). In *Separation: Anxiety and Anger,* Bowlby (1973) wrote that "the regulatory systems that maintain a steady relationship between the individual and his familiar environment" (i.e., the attachment system) could be viewed as *complementary* to physiological systems that maintained survival (p. 149). In this review, we highlight how work by our group and others concurs with Bowlby's original ideas about correspondence between the attachment system and physiological regulation, and how they interact to promote adaptation to the environment. We specifically focus on individual differences in attachment orientations to adult romantic relationships, their associations with physiological processes, and implications for health. Moreover, building on existing perspectives that focus on stress reactivity and its role as a mediator between attachment and health outcomes (Diamond & Hicks, 2004; Pietromonaco, Uchino, & Dunkel Schetter, in press), we introduce another perspective: that stress-related physiological changes support the activities of the attachment behavioral system, particularly for insecurely attached individuals.

A brief overview of adult attachment

In adulthood, romantic partners serve as the primary attachment figures (Hazan & Shaver, 1994). When the attachment system is activated during times of threat, uncertainty or distress, individuals seek proximity and support from attachment figures, who serve as a *safe haven* by providing support and comfort. When the attachment system is not activated, individuals use the symbolic or actual presence of attachment figures as a *secure base* to more confidently explore novel environments, pursue goals and attain personal growth strivings. As a secure base, attachment figures provide a safe place to retreat should exploration or goal pursuit become too difficult or threatening. Thus, the three key features of attachment bonds are a desire to maintain proximity to attachment figures, increased distress during prolonged or unwanted separations, and the use of attachment figures as a safe haven and a secure base (Hazan & Zeifman, 1999).

Individual differences in attachment develop through interactions with early caregivers and other attachment figures over the lifespan. These interactions shape expectations about the trustworthiness of others, perceptions of self-worth, and emotion regulation strategies. Individual differences in attachment are generally conceptualized along two continuous dimensions: anxiety and avoidance (Brennan, Clark, & Shaver, 1998). The attachment anxiety dimension is characterized by fear of and worry about rejection, abandonment and being unloved. Individuals high in attachment anxiety have heightened arousal, difficulty with emotion regulation and demonstrate greater hypervigilance to threatening cues (Collins & Feeney, 2000; Mikulincer & Shaver, 2008). The attachment avoidance dimension is characterized by a lack of comfort with intimacy and dependence on others. Individuals high in attachment avoidance perceive support more negatively and tend to dismiss, deny or downplay needs, worries or potential threats (e.g., Collins & Feeney, 2004; Mikulincer & Shaver, 2008). Attachment security (low anxiety and avoidance) is characterized by comfort with intimacy and confidence of others' love and care. Individuals high in attachment security are readily able to regulate their emotions, are comforted by support and report being in high-quality and well-functioning romantic relationships (e.g., Collins & Read, 1990; Mikulincer & Shaver, 2008).

Attachment insecurity is characterized as being high in attachment anxiety, avoidance or both (e.g., preoccupied/anxious, dismissing or fearful attachment).

The physiological regulatory systems that are impacted by the attachment system include *allostatic* and *restorative* processes (Robles & Carroll, 2011). Allostatic processes, based on the concept of allostasis (survival through change), are biological processes that have a broad range of function, such that survival depends on being able to change biological set points temporarily (McEwen, 1998). The prototypical allostatic processes are neuroendocrine and immune changes that occur *during* psychological and physical stress, which are mobilized during challenge and return to normal, basal levels after challenge. For example, to survive a physical attack, the sympathetic nervous system (SNS) and hypothalamic-pituitary-adrenal (HPA) axis release hormones (catecholamines and cortisol, respectively) that provide energy to the brain and enable physiological responses that support a fight-or-flight response.

In contrast, *restorative* processes respond *following* the cessation of environmental challenges, when allostatic processes return to normal, steady-state levels. Examples include sleep, tissue repair, and biological processes involved in growth and energy storage (Robles & Carroll, 2011). Restorative processes are downregulated (partly or entirely) during challenge to redirect energy consumption towards allostatic processes, and return to pre-challenge states following the cessation of challenge. In general, restorative processes are complementary to allostatic processes, and both contribute to long-term health outcomes. In addition, the attachment system likely influences restorative processes through HPA axis hormones and autonomic nervous system output, which are also involved in allostatic processes (McEwen, 1998). However, most of the extant research on attachment and physiology examines allostatic processes, which we review below. First, we describe research on normative attachment functions, followed by studies examining individual differences in attachment. Later, we discuss preliminary work by our group suggesting associations between individual differences in attachment and restorative processes.

The attachment system and allostatic processes

Normative attachment functions

Despite calls for better understanding of the normative psychobiological functions of the attachment system vis-à-vis the formation, maintenance, function, and the loss of attachment bonds (Diamond, 2001; Sbarra & Hazan, 2008), there is relatively little research on the normative functions of the attachment system and allostatic processes in adults. The prevailing view is that attachment bonds function to maintain felt security (Bowlby, 1969; Sbarra & Hazan, 2008) by attenuating psychological and physiological stress reactivity (Diamond & Hicks, 2004) and by potentially serving as psychobiological regulators of felt-security (Sbarra & Hazan, 2008). For example, the presence or symbolic presence (e.g., a picture) of a romantic partner attenuates threat-related neural activity during mild shocks (Coan, Schaefer, & Davidson, 2006), reduces perceptions of pain in response to heat stimuli (Master et al., 2009), and reduces self-reported stress (Kane, McCall, Collins, & Blascovich, 2012). Additionally, perceiving greater available support is associated with better indices of physical health (Holt-Lunstad, Smith, & Layton, 2010; Uchino, 2009) potentially due to bolstered feelings of felt-security or knowing that close others will be there during times of need.

Social support processes, particularly the provision and receipt of support in the context of close relationships, have been conceptualized from a normative attachment perspective (Collins & Feeney, 2010; Collins & Feeney, 2000). However, results are inconsistent regarding the effects of receiving social support from close others (McClure et al., in press). For example, receiving support may exacerbate negative affect (Bolger & Amarel, 2007) and physiological responses to stress (Kirschbaum, Klauer, Filipp, & Hellhammer, 1995). According to attachment theory, attachment figures must be responsive in order to optimally promote felt-security and positive well-being (Kane et al., 2012). So, the effectiveness of support provided may hinge on several factors including the needs of the recipient, the skill of the support provider, and the type and timing of support provided (Collins & Feeney, 2010). We note that research on social support typically extends beyond attachment figures (i.e., to friends, coworkers, and entire social networks; Diamond, 2001), and the support literature, as a whole, can only serve as a proxy for understanding normative attachment functions.

The threat of separation from attachment figures (e.g., conflict), prolonged separations, unwanted separations and loss (e.g., divorce, death, relationship dissolution) causes distress and may exacerbate the effects of other stressful events. An extensive review of marital war-time or job-related separations revealed that prolonged separations, especially those that are novel and occur on an irregular basis, are associated with elevated depressive, anxiety, and physical symptoms, sleep disturbance, and loneliness (Vormbrock, 1993). Even in more routine circumstances, couples separating at the airport demonstrated more contact and proximity-seeking behaviors and greater displays of sadness than couples traveling together prior to separation (Fraley & Shaver, 1998). Behavioral consequences of separation distress are well-documented in animal models (Polan & Hofer, 2008) and infant-parent dyads (Ainsworth & Bell, 1970), but much less is known about allostatic responses to short-term separations in adulthood. Finally, attachment bonds may serve a physiological regulatory function through co-regulation or attunement (Sbarra & Hazan, 2008). From this perspective, everyday interactions with attachment figures serve to regulate physiological functioning even in the absence of threat.

These regulatory functions may be “hidden” and not exposed until separation (Hofer, 1984). When attachment bonds are disrupted, the physiological and psychological underpinnings of felt security become dysregulated and can manifest in a number of ways, such as HPA and SNS dysregulation, or sleep disturbance. In general, more work is needed to understand the normative physiological effects of felt security, social support, and co-regulation.

Individual differences

The links between normative attachment functions and allostatic processes in adulthood are likely influenced by individual differences in the attachment behavioral system. The primary approach by most research teams to probing individual differences and physiology involves 1) assessing individual variation in attachment anxiety and avoidance, and 2) relating those differences to allostatic processes assessed during psychological challenge. We highlight work by our group and others on allostatic responses to relationship-related stressors, followed by a brief review of responses to non-relationship related stressors.

Relationship-related stressors. Interpersonal exchanges between intimate partners are always a double-edged sword: On one hand, exchanges with partners can lead to receiving support and increasing closeness (Pasch & Bradbury, 1998); on the other hand, such exchanges can also lead to increased negativity and increasing separation. Thus, we and others use interpersonal exchanges to understand how individual differences in anxiety and avoidance modulate physiological responses to attachment-related challenges. Although most exchanges in the laboratory involve discussing problems that each partner wants to change in the relationship (Roberts, Tsai, & Coan, 2007), some studies include discussing things that individuals would like to change about themselves in an attempt to elicit social support (Pasch & Bradbury, 1998). Most work focuses on HPA axis activity, but a few have examined SNS activation; such studies show that greater attachment insecurity is associated with elevated skin conductance levels during problem discussions (Holland & Roisman, 2010; Roisman, 2007).

In a sample of young, committed dating couples, we examined associations between individual differences in attachment and cortisol responses to two 20 minute interpersonal exchanges on separate days (Brooks, Robles, & Dunkel Schetter, 2011). On one day, couples discussed problems in their relationship, and on a separate day, couples discussed personal concerns focused on things about themselves they would like to change (order was counterbalanced). Our design allowed us to examine HPA axis responses in two different contexts that afforded opportunities to increase closeness by potentially resolving problems or providing support to each other, or decrease closeness by expressing hostility or providing inadequate support to each other. We collected saliva samples just before receiving instructions for the discussion task, and 40 and 90 minutes after the discussion to capture peak reactivity and recovery, respectively. We used the Experiences in Close Relationships – Revised scale (Fraley, Waller, & Brennan, 2000) to assess attachment anxiety and avoidance from both partners and test the effects of participant (actor) and partner attachment on cortisol responses.

Greater anxiety and avoidance were related to elevated baseline cortisol levels just prior to receiving instructions for the discussion tasks. These data are consistent with other work showing elevated cortisol levels in insecure individuals just prior to relationship discussions (Powers, Pietromonaco, Gunlicks, & Sayer, 2006). In our study, couples knew that they were going to participate in a relationship discussion task, although at the time of the baseline sample couples did not know which type of discussion would be taking place. Thus, even in anticipation of a challenge to the attachment system, insecure individuals initiate an HPA axis response.

During the discussions, we found a different pattern of associations for men and women. For men, greater actor anxiety was associated with larger increases in cortisol during the problem discussion, as shown in the top line in Figure 1. For women, greater *partner* avoidance was associated with larger increases in cortisol during *both* the problem and personal concern discussions, shown in bottom two lines in Figure 1. Thus, for women in our sample, having a partner with who is uncomfortable with closeness may elicit greater HPA activation. Perhaps highly avoidant partners are more detached and withdrawn during the discussions, which women may perceive as uncontrollable and/or a form of social rejection thus eliciting a cortisol response (Dickerson & Kemeny, 2004). Indeed, among married couples, husbands' withdrawal following wives' demands during a problem discussion was associated with elevated wives' cortisol levels over the course of the subsequent day (Kiecolt-Glaser et al., 1996). Notably, our study was the first to demonstrate effects of individual differences in attachment on cortisol responses to personal concern discussions that intended to elicit social support.

Non-relationship stressors. Beyond relationship-related challenges, another way to examine how individual differences in the attachment behavioral system influence physiology is through non-relationship related challenges used in research on acute stress. Unfortunately, clear patterns have been difficult to discern because of the wide range of challenging tasks across studies. For example, greater attachment anxiety was related to both elevated reactivity to uncontrollable acoustic startle in young women (Quirin, Pruessner, & Kuhl, 2008) and blunted cortisol reactivity in response to a series of non-relationship related stressors (mirror tracing, Stroop color interference) in middle-aged and older adults (Kidd, Hamer, & Steptoe, 2011). Beyond differences in the stressful tasks, another explanation for the diverging results is that older adults with greater attachment anxiety may have been exposed to (or generated through personality influences on the surrounding environment) more relationship challenges over time. This exposure may initially contribute to hyperactive cortisol responses and eventually contribute to neuroendocrine changes leading to HPA hyporesponsiveness (Lovallo, 2011).

Surprisingly, few studies have examined associations between attachment anxiety and autonomic activity. One study showed that greater anxiety was associated with lower skin conductance levels (Diamond, Hicks, & Otter-Henderson, 2006). However, avoidance appears to be associated with greater sympathetic nervous system reactivity across several stressful tasks as indexed by skin conductance levels (Diamond et al., 2006), and greater parasympathetic nervous system withdrawal during several stressful tasks as indexed by high-frequency heart rate variability (Maunder, Lancee, Nolan, Hunter, & Tannenbaum, 2006).

Summary. Thus far, the extant data from our group and others suggest that greater attachment anxiety is associated with a greater anticipatory HPA axis response just prior to attachment-related challenges (relationship discussions), while more equivocal evidence suggests greater reactivity during relationship discussions (Powers et al., 2006). Importantly, we note that most studies of relationship-related stressors have focused on relationship discussions, rather than short-term relationship separations which should also activate the attachment behavioral system. Notably, individuals with high attachment anxiety experienced elevated daily cortisol during a travel-related separation period compared the pre-separation period and those low in attachment anxiety (Diamond, Hicks & Otter-Henderson, 2008). In terms of attachment anxiety and responses to non-attachment related challenges, studies are equivocal due in part to differences in stressful tasks and samples (younger vs. older adults). Individuals with high attachment avoidance show greater anticipatory responses to relationship problem discussions, evoke greater HPA axis responses in their partners, and show greater HPA and SNS responses to non-relationship related stressors. Finally, thus far no studies suggest associations between individual differences in attachment security and recovery from stressors. Taken together, greater insecure attachment is associated with anticipatory responses to relationship-related stressors, with mixed evidence for reactivity during non-relationship-related stressors more generally. Thus, for secure individuals, as Bowlby (1973) wrote, “so long as the systems that maintain an individual within his familiar environment are successful, the loads placed on the systems that maintain physiological states steady are being eased” (p. 149). In the next section, we discuss the potential adaptive value of these responses for the attachment behavioral system.

Allostatic processes as part of the attachment behavioral system?

The allostatic changes in insecure individuals (in the context of attachment) reviewed in the previous section are typically thought of as a consequence of encountering attachment-related challenges such as rejection, excessive closeness, and/or the threat of social evaluation related to being observed in a laboratory environment. Physiological responses are typically conceptualized as outcomes (i.e., the “loads” from the previous Bowlby quote) that reflect the effects of attachment-related challenges on insecure persons (Diamond & Hicks, 2004), and mediators of associations between insecure attachment and physical health outcomes (Pietromonaco et al., in press). Another complementary, non-mutually exclusive conceptualization is that allostatic responses may support the attachment behavioral system in helping the individual adapt to their environment. That is, in addition to being consequences of attachment-related challenges, HPA and autonomic reactivity during challenge may aid the normative activities of the attachment system, particularly for insecure individuals. Here, we propose one way that HPA and autonomic activity might help the attachment system carry out its normal functions: By providing energy to the brain in preparation for and following attachment-related challenges to facilitate social-cognitive processing and emotion regulation.

Human studies of the neuroscience of attachment have been accumulating in the past decade, and while not all studies converge on the same brain regions, there is notable empirical convergence in the neural circuitry related to social threat. Regions that are frequently implicated in the literature on social threat include the amygdala, insula, and regions in the medial prefrontal cortex (e.g., dorsal anterior cingulate [dACC]; reviewed in Vrtička & Vuilleumier, 2012). Regarding normative processes, receiving support from an intimate partner (Coan et al., 2006) or viewing pictures of intimate partners (Eisenberger et al., 2011) while experiencing pain (electric shock or heat stimuli, respectively) reduced neural activity in regions implicated in social threat and physical pain. In terms of individual differences, individuals reporting greater attachment anxiety showed greater activity in social threat-related regions during a simulated social rejection task (dACC and insula, DeWall et al., 2012), and viewing an angry face when performing incorrectly on a dot-counting task (amygdala, Vrtička, Andersson, Grandjean, Sander, & Vuilleumier, 2008). Brain regions involved in social approach and reward (Vrtička et al., 2008), emotion regulation, and reading the mental states of others are also implicated in the attachment behavioral system (Vrtička & Vuilleumier, 2012), suggesting several sets of neural circuits that may constitute the attachment system.

Despite its small size relative to the rest of the body, the brain is a major consumer of energy in the form of blood glucose (Peters et al., 2004). Indeed, “selfish brain” theory proposes that biological mechanisms in the body and central nervous system are designed to prioritize the central nervous system in energy consumption. Primary among those are the HPA axis and SNS, which play a key roles in energy metabolism (Sapolsky, Romero, & Munck, 2000). Cortisol and catecholamines (produced by the SNS) induce insulin resistance in their target cells. When the hormone insulin binds to its receptor on muscle and fat cells, blood glucose is transported into cells and stored as glycogen. Insulin resistance occurs when cells are unable to "hear" the insulin signal, and consequently have reduced ability to take up blood glucose (Stumvoll, Tataranni, Stefan, Vozarova, & Bogardus, 2003). Moreover, both cortisol and catecholamines induce the manufacture of glucose in the liver through several processes (Sapolsky et al., 2000). Conceptually, cortisol and catecholamine signaling should lead to increased availability of circulating blood glucose, although the actual process may be more complicated and may depend on recent glucose consumption (Voege, Moghaddam Jaffary, & Robles, under review). Regardless, the brain is a major consumer of energy, and the HPA axis and SNS play key roles in regulating energy availability to the brain and body.

A key question is when such energy would be made available relative to an attachment-related challenge, such as relationship conflict. On one hand, SNS responses to challenge are observed within minutes of challenge, terminating relatively quickly after the challenge ends. On the other hand, peak cortisol responses to challenge are observed 20 - 40 minutes later, and terminate after more than an hour (Dickerson & Kemeny, 2004). SNS responses to challenge might make energy available "in the moment" to help the individual cope with an attachment-related challenge. However, the longer timeframe of cortisol responses makes it implausible that glucose would be immediately available as a direct consequence of a specific relationship conflict discussion. For example, in our dating couples study described earlier, cortisol reactivity was defined by changes from baseline to 40 minutes after the beginning of the discussions, which were only 20 minutes in length. Thus, peak cortisol reactivity to laboratory-based challenge was observed *after* the challenge ended, and subsequent biological effects on glucose metabolism would also occur after the discussion was over. At the same time, our work and others' research also suggests that insecure attachment is associated with greater cortisol levels during baseline, when individuals are *anticipating* attachment-related challenge. If cortisol elevations began prior to challenge, such elevations would likely persist throughout the discussion. Moreover, circulating cortisol levels can work synergistically with catecholamines to elevate circulating glucose levels (Sapolsky et al., 2000).

How might an increase in energy availability be adaptive for insecure individuals before, during, and after attachment-related challenges? Several neural regions implicated in the attachment system are large consumers of the brain's "alternative energy" source (supplied by a process called aerobic glycolysis), which suggests high energy consumption more generally (Figure 4a in Bullmore & Sporns, 2012; Vaishnavi et al., 2010). Those regions include orbitofrontal cortex, anterior cingulate, posterior cingulate/precuneus, and regions within prefrontal cortex. With that in mind, we suggest that for insecurely attached individuals, HPA axis and SNS activation in anticipation of an attachment-related challenge may increase overall glucose available for use by the brain, which would then be consumed in areas involved in emotion regulation and reading the mental states of others during and potentially after relationship stressors. Although this process may occur normatively, the attachment systems of insecure individuals may be wired through experience to expect a greater load on emotion regulation systems, thus requiring greater allostatic responses (more "requests") to increase available blood glucose. Indeed, social baseline theory posits that individuals outsource their emotion regulation capacity to others, and having (or perceiving) a less adequate network should increase the emotion regulation "load" (Coan, 2008), which may require more energy in the form of glucose to handle those processing needs.

The effectiveness of self-control efforts, including emotion regulation, may be a function of blood glucose (Gailliot et al., 2007). The original “limited energy resource” model proposed that circulating blood glucose represented the fuel needed by the brain to engage in self-control (Gailliot et al., 2007), but this explanation has been challenged by contradictory findings (Hagger & Chatzisarantis, 2013; Kurzban, 2010; Molden et al., 2012; Sanders, Shirk, Burgin, & Martin, 2012). Furthermore, an alternative explanation is that glucose levels in the brain (that cannot be indexed by measuring blood glucose) may be redirected to specific brain regions depending on situational demands, and that ineffective self-control is due to the brain shifting energy away from regions involved in self-control to other regions (Beedie & Lane, 2012). Even though the association between blood glucose and self-control is more complicated than originally thought, we note that research on self-control and glucose has primarily focused on complex cognitive tasks (e.g., anagrams, arithmetic, often involving divided attention) that are typically devoid of needing to control emotional expressions or read the mental states of others. In contrast, attachment-related challenges involve multiple socioemotional and cognitive functions including impression management, emotion regulation, and reading the mental state of one’s significant other, which together may involve greater energy requirements than cognitive tasks in self-control studies. Thus, attachment-related challenges may support the social cognitive and emotion regulatory functions of the attachment behavioral system via regulating energy supply to the brain, with magnified associations for insecure individuals. Importantly, empirical studies designed to test such assertions are needed.

Although speculative, one implication of increased demand for fuel for emotion regulation in insecure individuals is increased energy consumption (eating) as a way to cope with attachment-related challenge, or even shifts in preferences for certain types of foods. Several lines of work suggest this possibility. In animal models, exposure to chronic stress (and subsequent HPA axis activation) not only increases food intake, but also contributes to increased preference for energy-dense “comfort” foods that are high in fat and glucose content, which in turn dampen HPA axis activation (Dallman et al., 2003). Interestingly, in a sample of women, those who showed greater cortisol responses to a stressor consumed more calories and showed a greater preference for sweet foods (Epel, Lapidus, McEwen, & Brownell, 2001). In experimental studies, social rejection by peers led to overeating in college students (Experiment 2, Baumeister, DeWall, Ciarocco, & Twenge, 2005) and increased motivation to earn points towards snack foods in adolescents (Salvy et al., 2012). Overall, the links among attachment insecurity, the energetically costly neural circuitry involved in emotion regulation, the role of the HPA axis in providing energy to the brain, and the potential need for increased “fuel” during chronic stress and social rejection are speculative, but they suggest promising avenues for future research. Moreover, they highlight one insight generated by viewing allostatic responses as a part of the attachment behavioral system, again presciently noted by Bowlby (1973) that “so long as the systems maintaining physiological homeostasis are successful…the easier it will be for him to maintain himself effectively within his familiar environment” (p. 150).

What are the consequences for physical health?

Thus far, we have discussed how activation of the attachment system and individual differences in the attachment system are associated with allostatic processes that have implications for health. However, measures of HPA axis and SNS function are not health outcomes by themselves. This point is critical, as biobehavioral research in this domain and others occasionally equates physiological variables like cortisol responses as health outcomes, when those biological markers are merely biological mediators without immediate clinical relevance. Indeed, the National Institutes of Health proposed terms and definitions to guide research and clinical applications of biological markers, differentiating among *clinical endpoints*, *surrogate endpoints*, and *biomarkers*, where clinical and surrogate endpoints are considered "health outcomes"[1]. We and others further differentiate *biological mediators* from the broader class of biomarkers (Miller, Chen, & Cole, 2009; Robles, Slatcher, Trombello, & McGinn, 2013). Although HPA and SNS function is related in theory to clinical endpoints within a biologically plausible mechanistic chain, there is not sufficient evidence to raise HPA axis, GSR, or heart rate variability changes to interpersonal discussions above *biological mediator* status.

For example, an allostatic process that is gaining empirical interest is inflammation, the body's immediate response to injury and infection. Married individuals reporting greater attachment avoidance showed increased 24-hr production of the inflammatory marker interleukin-6during hospital visit involving a relationship problem discussion compared to a visit involving a personal concern discussion (Gouin et al., 2009). Chronic and persistent inflammation contributes to accumulating damage in tissues surrounding sites of chronic infection, and may be a central mechanism explaining how psychosocial factors play a role in chronic disease, including atherosclerosis and cancer (Miller et al., 2009). However, with the exception of the biomarker C-reactive protein, most measures of inflammation including interleukin-6 do not have a sufficient evidence base to be considered surrogate markers for cardiovascular disease (Ridker, Brown, Vaughan, Harrison, & Mehta, 2004).

[1] Briefly, clinical endpoints "reflect how a patient feels, functions, or survives" and are considered primary variables for measuring risks and benefits of randomized clinical trials, such as occurrence of a heart attack, symptoms of infection, or changes in quality-of-life (Biomarker Definitions Working Group, 2001). Surrogate endpoints are biomarkers that can substitute for clinical endpoints based on available evidence, such as cholesterol levels or blood pressure, which predict future cardiovascular disease and have clinical cut points. Biomarkers that are not considered surrogate endpoints, but have a plausible mechanistic role, can be described as *biological mediators*.

Restorative processes. Emerging data suggests that individual differences in the attachment system may also have implications for restorative processes. Two prototypical restorative processes are sleep, which is the one time in our lives when we are free of external challenges from the environment, and wound healing, which is a cascade of multiple cellular events initiated by damage to the skin. Importantly, measures of both processes can also be considered clinical endpoints.

Sleep. Sleep is physically restorative because of its role in physical growth and regulating energy metabolism and appetite (Robles & Carroll, 2011). Moreover, for the 70% of adults who report sleeping with a bed partner in a national survey (National Sleep Foundation, 2011), sleep is a dyadic behavior, and relationship quality may impact sleep and vice versa (Hasler & Troxel, 2010; Troxel, 2010; Troxel, Robles, Hall, & Buysse, 2007). Normative attachment processes regulate feelings of security, which in turn provide an optimal sleep environment. Secure individuals are comfortable with closeness and are comforted by the presence of their partners, leading to a sleep-conducive environment. Individuals high in attachment anxiety may be at risk for impaired sleep due to hypervigilance of partner's behavior, heightened arousal, and difficulty with emotion regulation. On the other hand, individuals with high attachment avoidance may be at risk for impaired sleep due to their lack of comfort with physical closeness.

In our dating couples study, we examined how attachment style interacts with the situational context to influence sleep (Kane, Brooks, & Robles, 2011). We focused on how much individuals disclose thoughts and feelings to their partners, which can increase intimacy (Laurenceau, Barrett, & Rovine, 2005). After their laboratory visits, partners completed a nightly diary assessing the degree to which they disclosed facts and information, thoughts, and feelings to their partner. In the morning, partners completed a sleep diary assessing the prior night's sleep efficiency (time asleep divided by total time in bed, expressed as a percentage) and subjective ratings of sleep quality the next morning ("poor" to "excellent"). Thus, we had two days of data on daily self-disclosure and sleep quality. For women, high attachment anxiety was associated with lower sleep efficiency and sleep quality, but the association was attenuated on the night that women reported relatively more self-disclosure (Figure 2A & B, left). Self-disclosure was not related to sleep quality among women high in avoidance; however, women low in avoidance reported better sleep quality on the night they reported relatively more self-disclosure (Figure 2B, right). For men, no interactions between attachment and self-disclosure emerged. Beyond demonstrating associations between individual differences in attachment and sleep, these data suggest that seeking support through disclosing thoughts and feelings to one's partner may have benefits for sleep among high anxious and low avoidant women.

Our data are consistent with the growing literature on attachment and sleep in adults. Attachment anxiety, but not avoidance appears to be related to greater sleep disturbance (Carmichael & Reis, 2005; Scharfe & Eldredge, 2001). In women with recurrent major depression, anxiously attached women had a lower percentage of slow wave sleep (the "deepest" stage of sleep), and this was particularly pronounced for women who were divorced, separated, or widowed (Troxel, Cyranowski, Hall, Frank, & Buysse, 2007). Similarly, among military veterans, greater attachment anxiety was related to lower percentage of slow wave sleep (Troxel & Germain, 2011). Among non-depressed women, greater attachment anxiety and avoidance were related to worse self-reported sleep quality (Maunder, Hunter, & Lancee, 2011). Finally, in a sample of couples, the association between relationship conflict and sleep quality was magnified for those high in attachment anxiety (Hicks & Diamond, 2011). In terms of normative processes, brief travel-related separations among spouses were related to greater sleep disturbance compared to before separation (Diamond, Hicks, & Otter-Henderson, 2008).

Skin repair. The skin provides a protective barrier for internal tissues against the outside world through physical, chemical, and biological means (for a brief, accessible review, see Robles & Carroll, 2011). The skin is highly innervated by the central nervous system and is a target for neuroendocrine factors involved in the stress response. In addition, chemical messengers in the immune system play significant roles in the barrier function of the skin, particularly restoration of the barrier following damage through physical injury. Even minor damage initiates an immediate cascade of immune-mediated events involved in skin repair.

Importantly, skin function is influenced by psychological stress and social bonds. Stressors including laboratory tasks, academic exams, and chronic stress were related to delayed skin barrier recovery, with a moderate effect size $r = -.38$ (Walburn, Vedhara, Hankins, Rixon, & Weinman, 2009). Social isolation and partner separation in rodents is also associated with slower wound healing (DeVries, Craft, Glasper, Neigh, & Alexander, 2007). Beyond the presence or absence of close others, the quality of close relationships is related to wound healing. Specifically, blister wound healing was slower during a hospital visit that included discussion problems in the relationship compared to a visit that included discussing personal concerns. Moreover, couples who showed more negative behaviors during both discussions had slower wound healing (Kiecolt-Glaser et al., 2005). Given that close relationships have implications for wound healing, individual differences in the attachment system should have impacts as well.

In our dating couples study, normal skin barrier function was disrupted using a tape-stripping procedure (repeated application and removal of cellophane tape from a small area on the lower forearm), followed by the relationship discussions that were described previously

(Robles, Brooks, Kane, & Dunkel Schetter, 2012). Skin barrier recovery was assessed by measuring moisture loss from the skin up to 2 h after skin disruption, using a device that measures changes in humidity and temperature just above the skin surface. We found that greater attachment anxiety in men and greater attachment avoidance in women was related to slower skin barrier recovery during the personal concern discussion as shown in Figure 3A and B. We posited that for men with high attachment anxiety, the personal concern discussion may be relatively more threatening because inadequate support provision may be construed as an indicator of the partner's lack of concern (Kane et al., 2012). For the women with high attachment avoidance, we speculated that the confines of the laboratory setting and discussion could be an aversive and inescapable stressor, leading to increased sympathetic activity in the skin (which we were unable to assess), which is associated with delayed wound healing in animal models (Souza, Cardoso, Amadeu, Desmouliere, & Costa, 2005).

Unexpectedly, we found that for women greater attachment anxiety predicted faster skin barrier recovery across both discussions (Figure 3B). Notably, animal research on social interactions and inflammation suggests that repeated experiences of social threat (e.g., defeat by an aggressive animal, or disruptions in social hierarchies) can increase HPA axis activity, and at the same time can prevent the HPA axis from suppressing inflammatory responses (Avitsur, Padgett, & Sheridan, 2006). This "preparative" response to threat may prime a rapid inflammatory response to injuries that may occur during acute stressors. Extending this conceptualization to our results, faster skin barrier recovery in women with high attachment anxiety may be a preparative response to expected social injury (inadequate support or rejection from an intimate partner). We note however, that demonstrating such a "preparative" response requires demonstrating elevated cortisol responses in high anxious women, which has not been observed in prior work (Brooks et al., 2011; Powers et al., 2006), and/or reduced HPA axis suppression of inflammation in the skin, which has not been studied in biobehavioral research.

Summary. Restorative biological processes that return the organism to steady-state functioning have received considerably less attention in research on attachment. However, emerging data suggest that insecurity is associated with disturbed sleep, and our preliminary data suggest that disclosure to intimate partners may attenuate such disturbances. Our work on skin repair adds to the catalog of biological systems that may be impacted by the attachment behavioral system. Collectively, our work highlights potentially complex associations between insecure attachment and restorative biological functions that merit exploration in future work.

Conclusions

Since Bowlby's prophetic assertions about the complementary roles of the attachment system and physiological responses, research on individual differences in adult attachment and their associations with physiology, especially allostatic processes, has progressed significantly. Across several independent studies, insecure attachment is associated with elevated HPA axis responses in anticipation of attachment-related challenges. Evidence is mixed regarding individual differences and reactivity to attachment-related challenges, and more work is needed to replicate our observed effects of partner avoidance on HPA reactivity. Our work suggests that insecure attachment may have implications for wound healing, and converging evidence from multiple groups suggests that insecure attachment is associated with sleep disturbance.

Most work to date has focused on associations between insecure attachment and physiological responses to relationship and non-relationship challenges. Although this paper is primarily focused on the role of dispositional characteristics we encourage increased attention to intersections between normative processes like support provision and receipt and allostatic and restorative processes. We also note that gender differences in the association between insecure attachment and physiology have often emerged in this work (e.g., Powers et al., 2006), including our work on cortisol, sleep, and skin barrier recovery. However, both the theoretical and empirical literature at this point, especially regarding individual differences in attachment, is still too small to draw any firm conclusions about gender differences. That said, current perspectives on social support (Taylor, 2011) and close relationships (Kiecolt-Glaser & Newton, 2001) suggest that the benefits of secure attachment and the costs of insecure attachment might be larger for women compared to men. However, a recent meta-analysis (Robles et al., 2013) suggests that if gender differences in the association between marital quality and health outcomes exist, they are likely small, thus requiring sample sizes much larger (in the multiple hundreds) than most studies on attachment and physiology. In addition, such differences may be primarily due to between-person variability in gender-related factors like social roles or individual differences in interpersonal orientations, rather than dichotomous biological sex (Kiecolt-Glaser & Newton, 2001; Robles et al., 2013).

More generally, viewing physiological changes as *supporting* the attachment behavioral system, rather than a mere consequence of its activation during challenge, may lead to new insights on connections between insecure attachment, physiology, and health. More generally, considering physiological processes as part of the individual's broader strategies for adapting to the environment may be a useful framework for understanding how personality and individual differences influence health. In the short-term, such strategies may have adaptive value, such as making energy available for social-cognitive processing and emotion regulation following attachment-related challenges. However, over the long-term the physiological changes described in this review may contribute to risk for chronic illness.

The most clinically relevant question is implications of insecure attachment for chronic disease-related clinical endpoints. Unfortunately, few data directly address that question. However, a recent cross-sectional study examined associations between individual differences in attachment and the prevalence of a number of chronic conditions in a nationally representative sample (N = 5,645; McWilliams & Bailey, 2010). Greater avoidant attachment was associated with higher prevalence of arthritis and a host of chronic-pain related problems. Greater anxious attachment was associated with higher prevalence of headaches, chronic-pain related problems, stroke, heart attack, high blood pressure, and ulcers. Importantly, these associations persisted even after adjusting for a number of demographic characteristics; and for anxious attachment, after accounting for lifetime history of psychopathology. Ultimately, studying the role of individual differences in chronic illness increasingly requires the development of biologically plausible models involving mechanisms directly related to disease onset and/or progression (Miller et al., 2009). Recent work on inflammation, and restorative processes like sleep and wound healing is facilitating conceptualizations of biologically plausible mechanisms that may link individual differences in attachment style to long-term health outcomes.

Bowlby (1973) wrote that his nascent attachment theory “place[d] the maintenance of a steady relationship between organism and familiar environment on a level of biological importance only one step lower than the maintenance of the much better understood physiological steady states”(p. 149). Four decades later, the biological importance of attachment theory has been raised considerably, providing a guiding and generative framework for understanding links between personality characteristics, socioemotional adaptation, biological processes, and health (Pietromonaco et al., in press).

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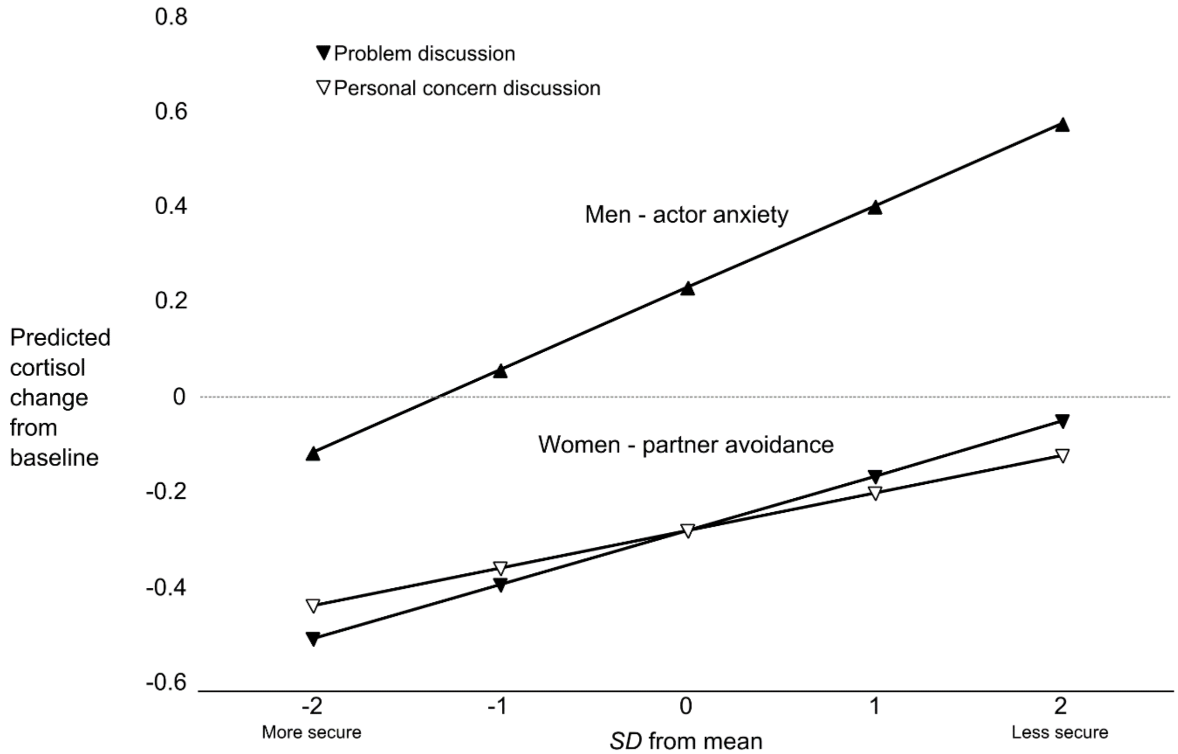

Figure 1. Associations between predicted cortisol change from baseline and actor anxiety in men during the problem discussion (triangles pointing up) and partner avoidance in women (triangles pointing down). The dotted line represents no change from baseline. Redrawn from Brooks et al. (2011).

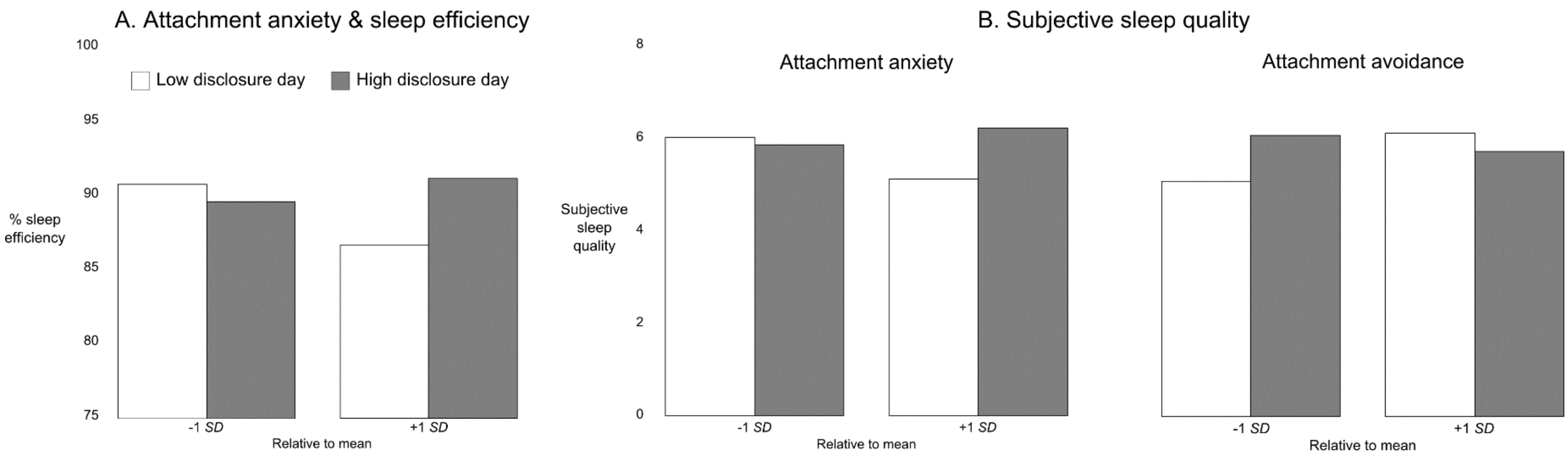

Figure 2. Sleep parameters over two days by individuals ± 1 *SD* from the mean on attachment security. A) Differences in % sleep quality between a relatively high vs. low disclosure day. B) Differences in subjective sleep quality between a relatively high vs. low disclosure day.

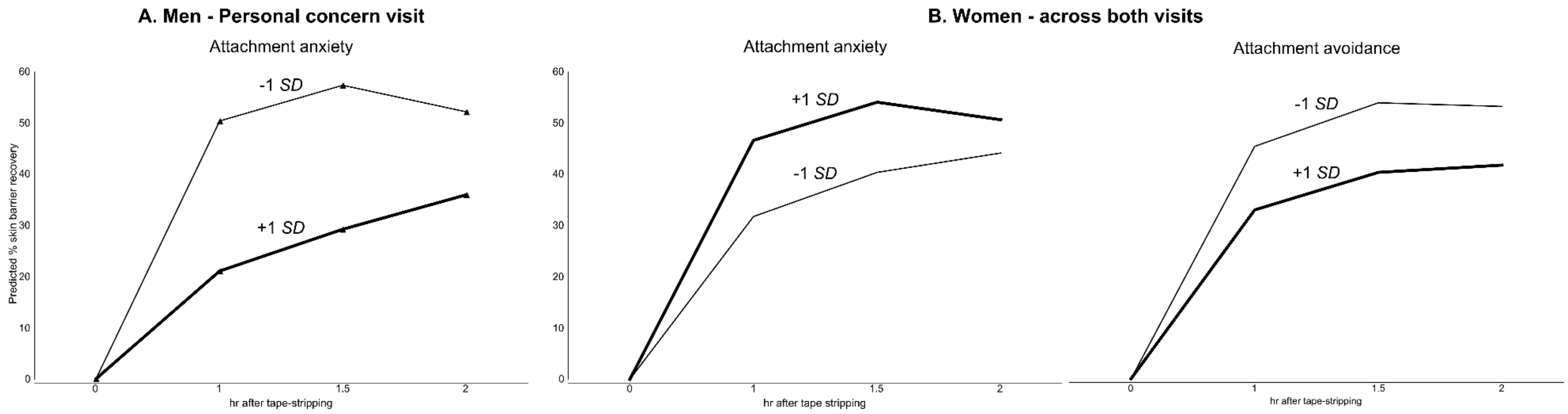

Figure 3. Predicted skin barrier recovery by attachment security for A) Men during the visit involving a discussion of personal concerns, and B) Women averaged across both visits. Redrawn from Robles et al. (2012).